Wind farm production estimates

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Wind Farm Production Estimates

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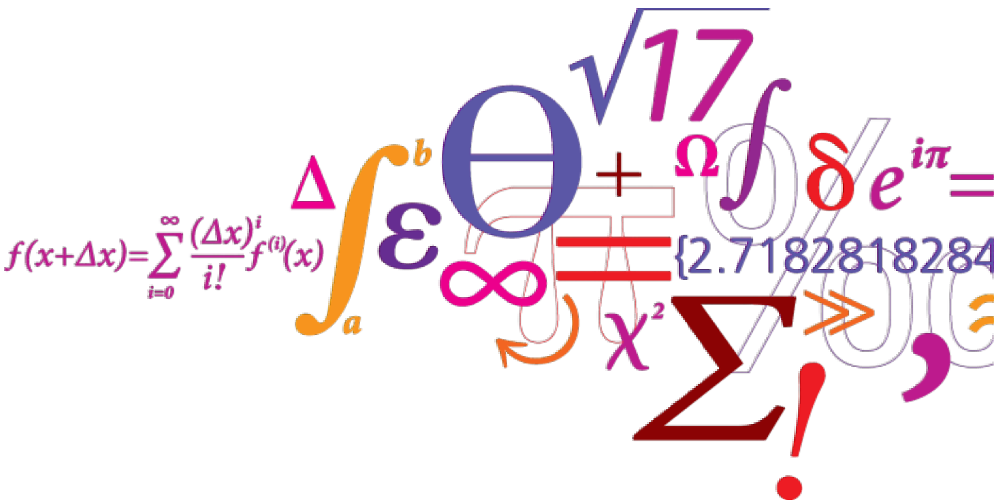


Wake effects:
What is it – and why is it so important?

The presence of neighbouring turbines causes:

Reduction in wind speed :
→ reduced power output

Increased turbulence :
→ increased loads

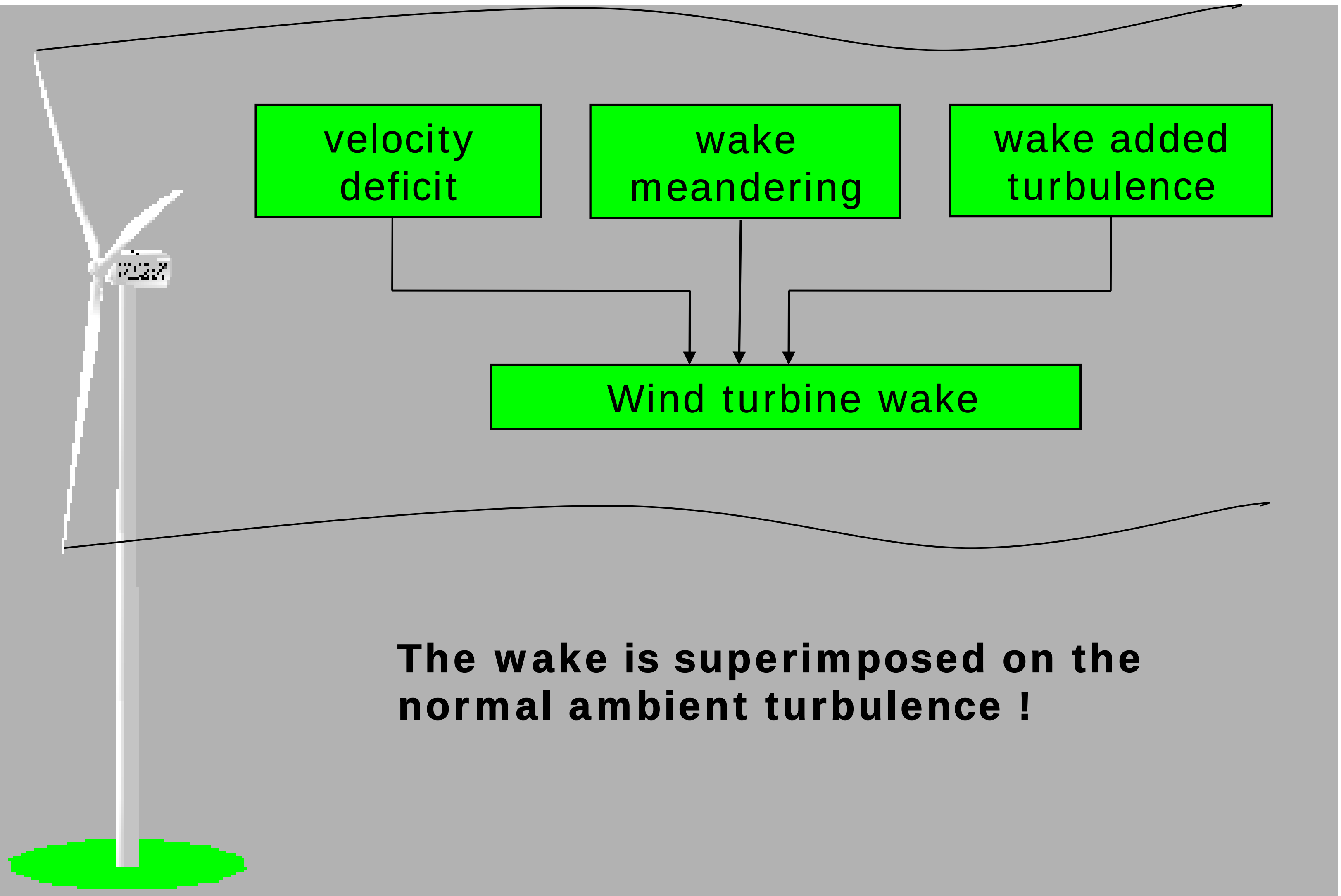
Though our primary focus is on loads the presented model is also capable of simulating power production.

- Which is the motivation of being in this particular session

Wake effects:

The basic idea of the Dynamic Wake Meander model (DWM)

- also some times called ”the poor mans LES”



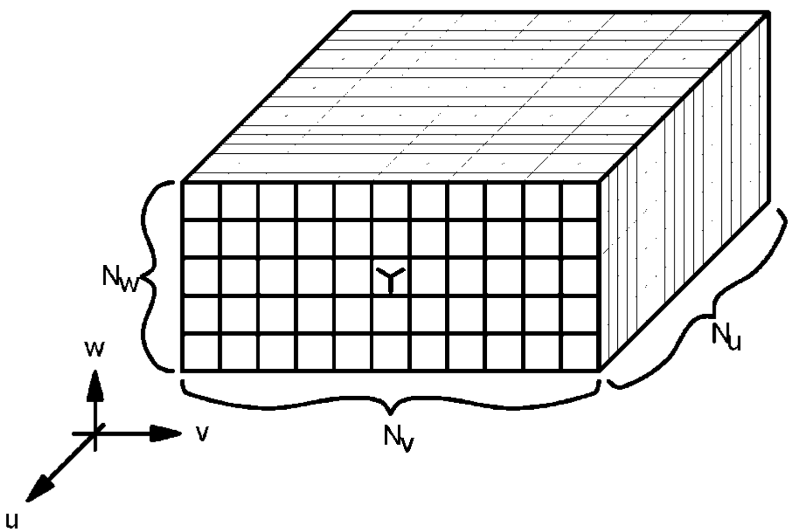
The wake is superimposed on the normal ambient turbulence !

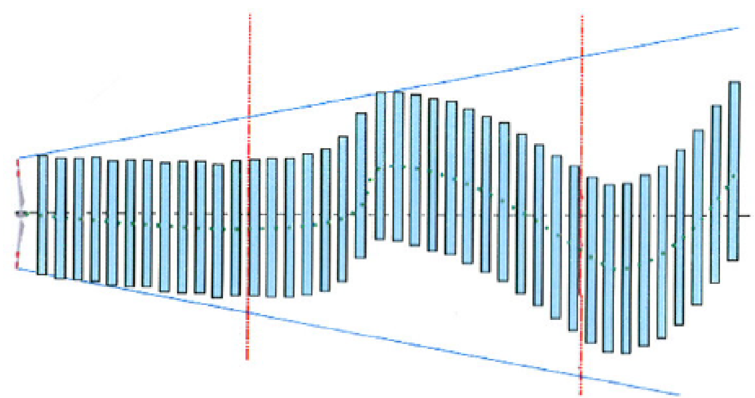
The Meandering

- A cascade of wake deficits are released from the upstream turbine
- Each deficit will be transported dowstream affected only by ambient large scale turbulence (like smoke from a chimney)
- It is the crosswind v,w velocities that dictates the deficit position

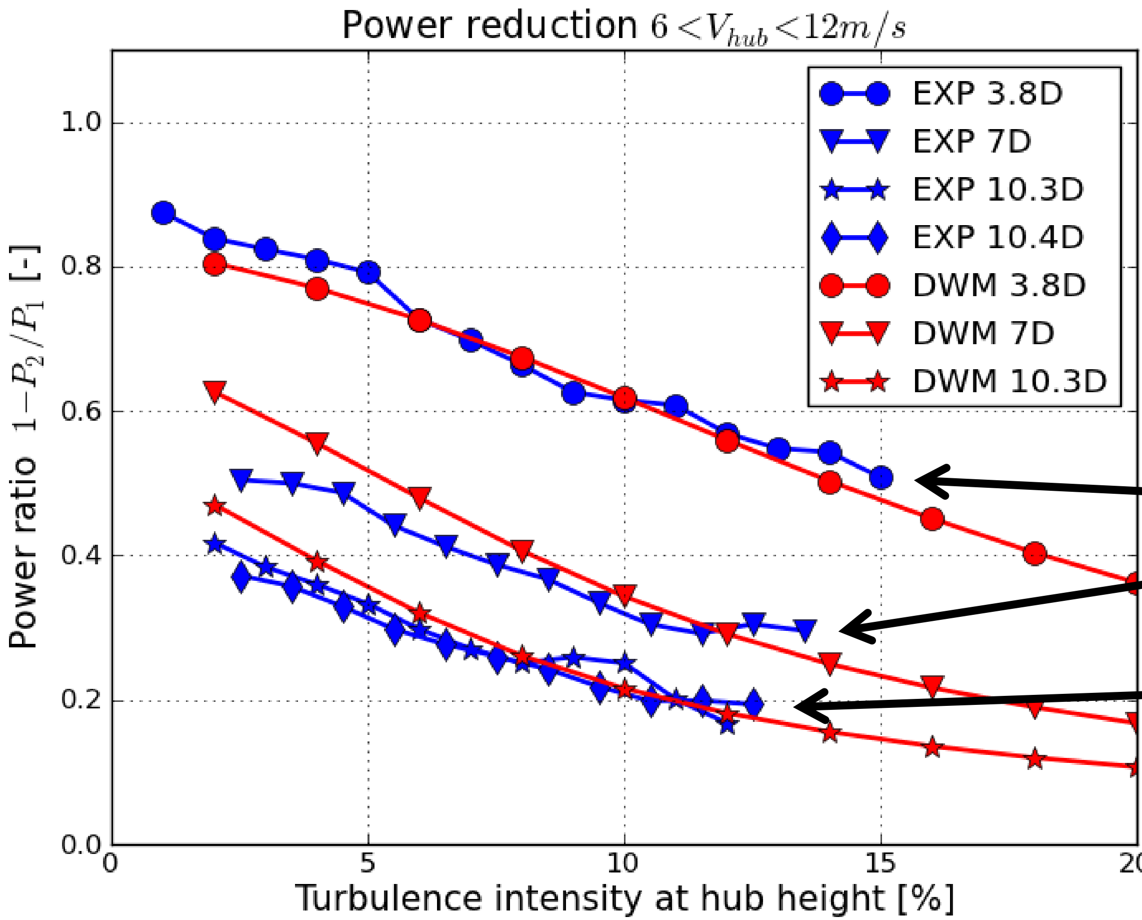
$$\frac{dy(t,t_0)}{dt} = v_c(y,z,t,t_0)$$

$$\frac{dz(t,t_0)}{dt} = w_c(y,z,t,t_0)$$





Validation for single wake situation



3.8D Wieringermeer

7D Horns rev

10.4D Horns rev

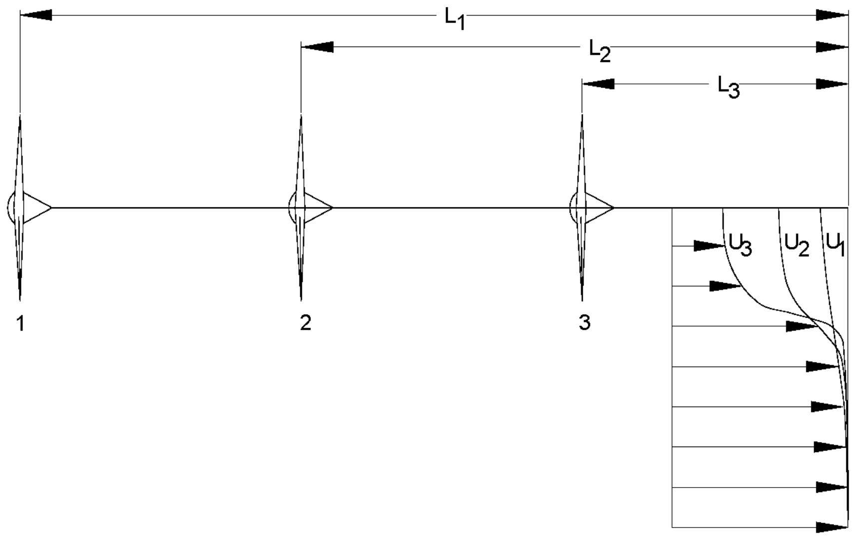
10.3 Nysted

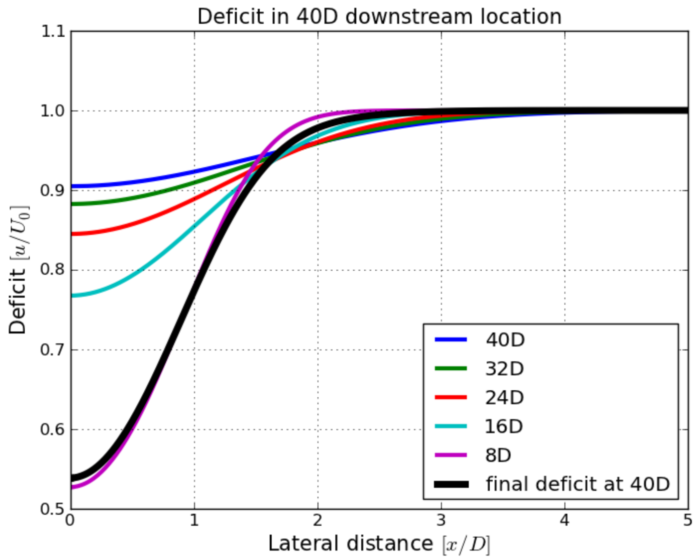
Increased turbulence causes higher production. The reason is increased turbulence mixing and an increased meandering.

T.J. Larsen, H. A. Madsen, G. Larsen, K. Hansen. *Validation of the Dynamic Wake Meander Model for Loads and Power Production in the Egmond aan Zee Wind Farm*. Submitted.

Wakes from multiple turbines

Ambient turbulence is low (2%), meandering is ignored



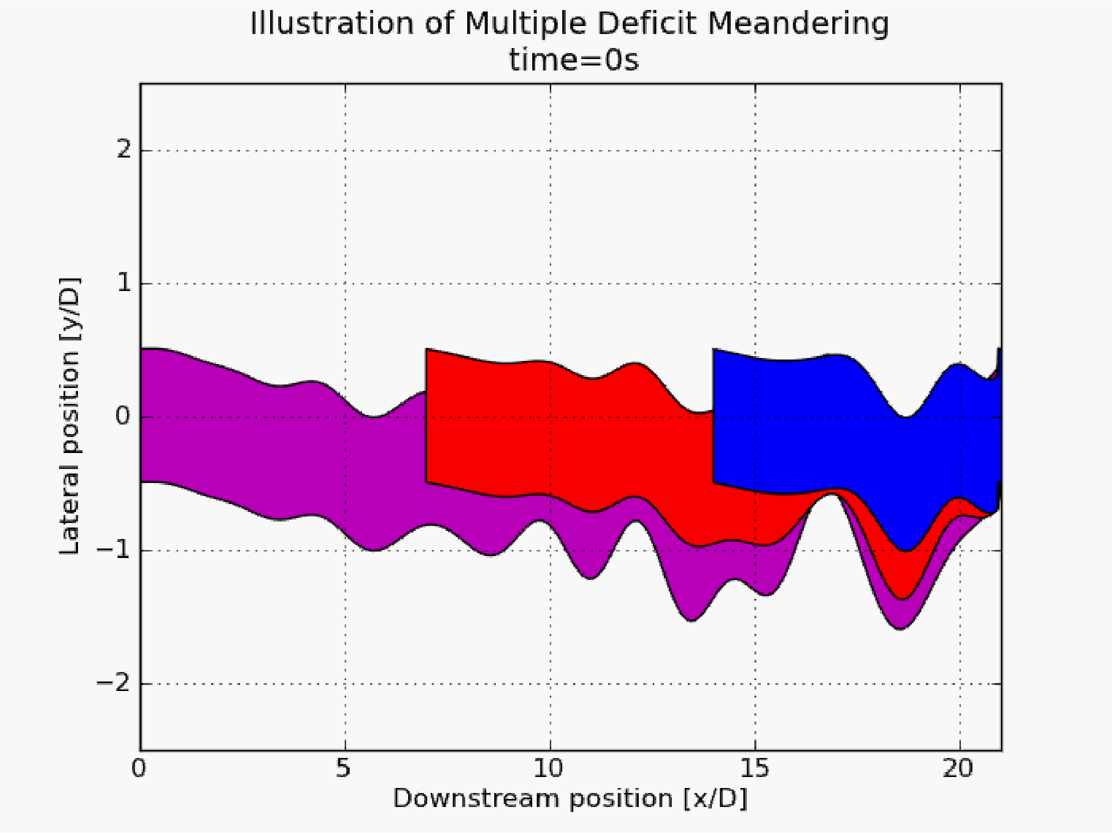


Deficits from individual turbines are compared with a more accurate solution including the wake of the upstream turbines.

The final deficit seem to be very well aproximated with the deficit of the nearest turbine (where free wsp was assumed)

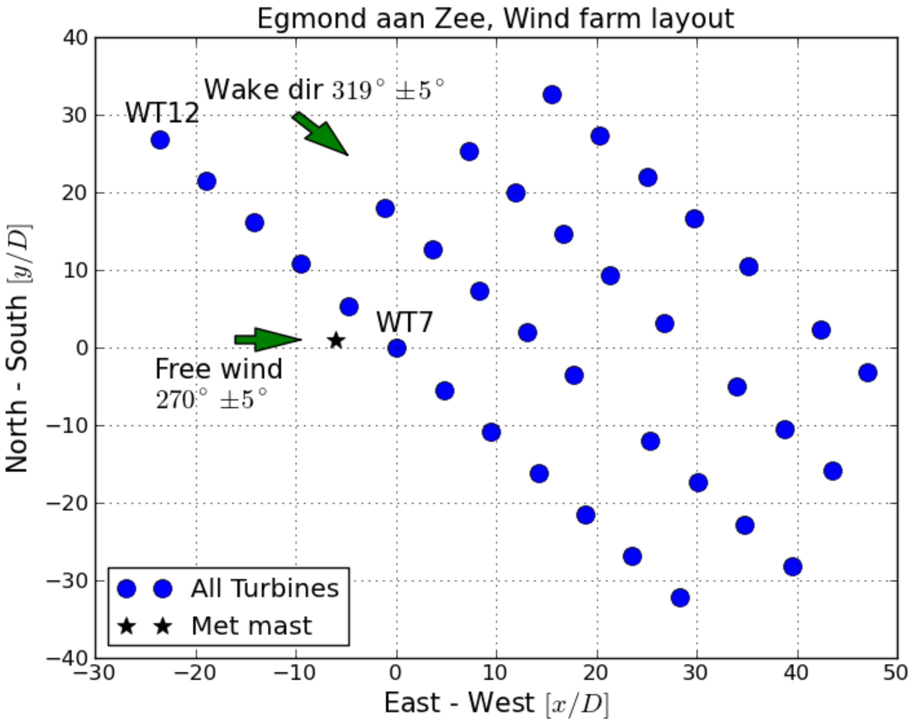
A good and practical approximation: $u_{def,final}(r) = \mathrm{MIN}(u_{def,i..N}(r))$

Meander path from multiple turbines
- a straight forward extension of DWM



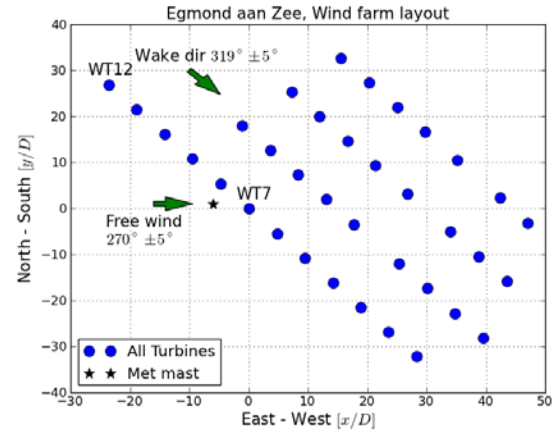
The wakes from two turbines (or more) only rarely coincide. Even in full wake direction, the path's will be different, which further justifies the simple selection proces.

Comparison of loads for the Egmond aan Zee windfarm



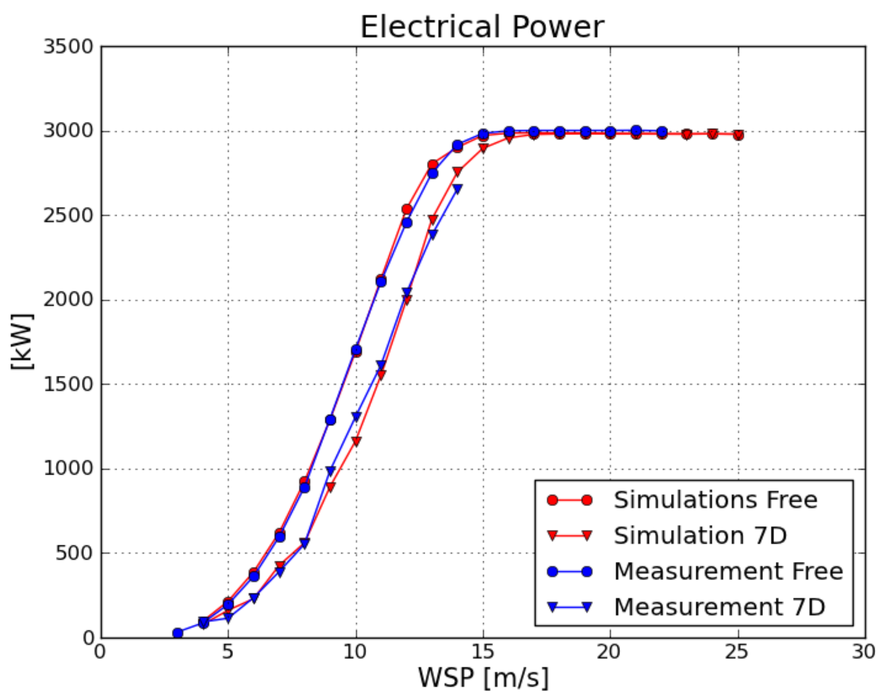
36 turbines installed in 4 rows. SCADA data for entire farm are monitored and detailed load measurements of WT7. MET mast data available. Please see the paper for information about calibration.

Comparison of power curves in free and wake conditions



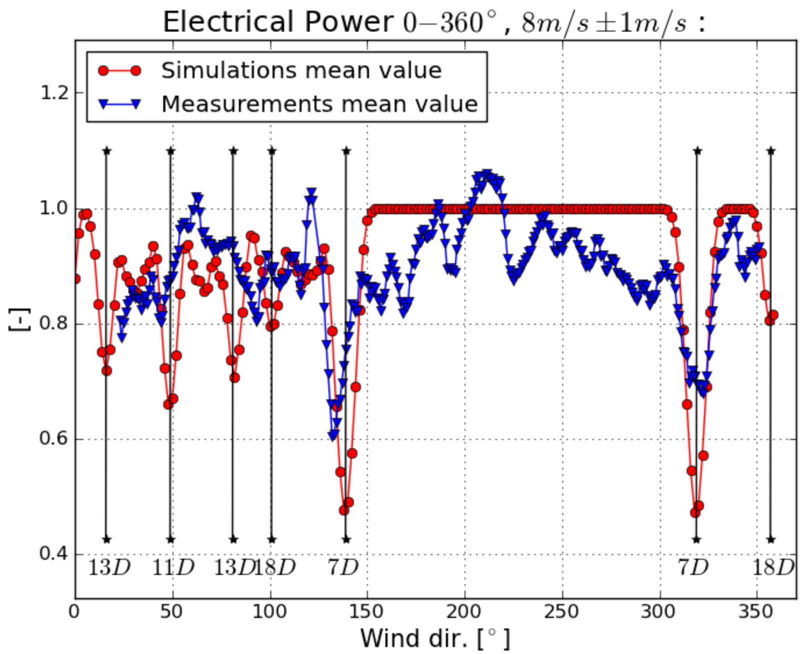
Every simulation point represents:
- 3 half-hour time simulations, each with
- Wind direction ±5°, ±2.5°, 0°

The turbine operates in wake of 5 upstream turbines!

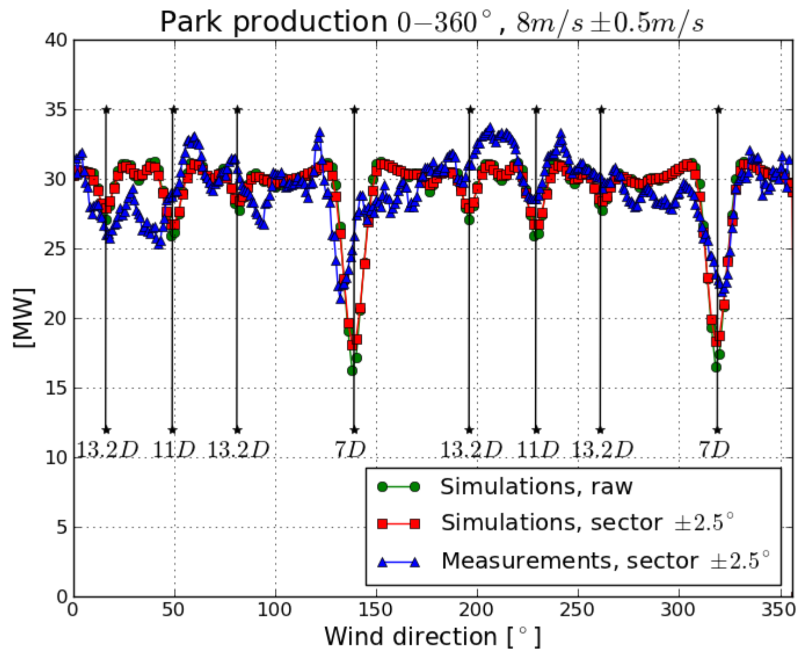


Power production for 0-360°, 8m/s

Single turbine

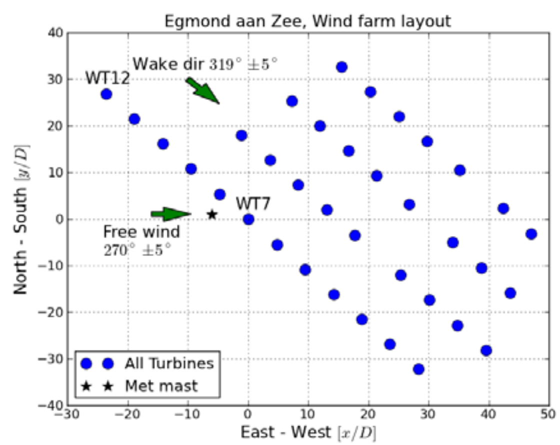


Entire wind farm



Power drops are seen in measurements and simulations for 7,11 and13D spacing.

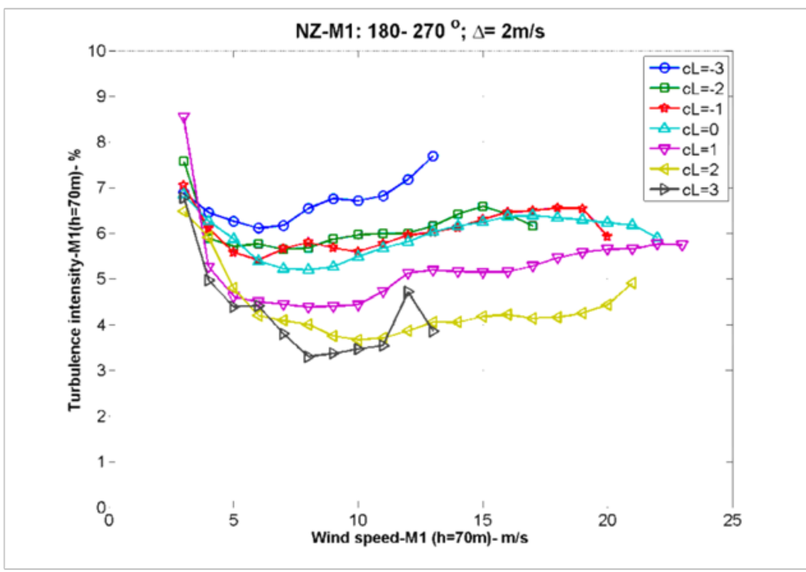
Differences may caused by sector averaging in measurements (direction and wsp) and lack of wind direction trends in the simulations.

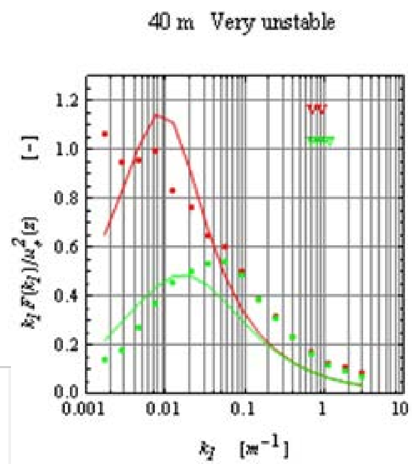


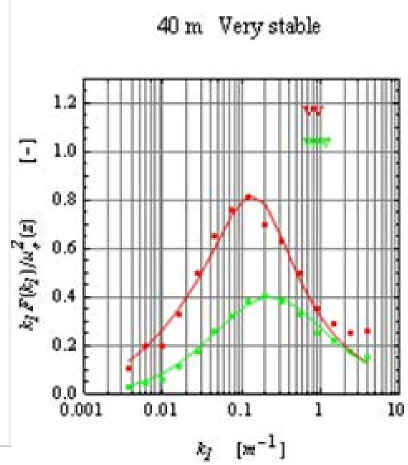
Influence of atmospheric stability

- The level of stability affect both the level of turbulence as well as the structure of turbulence

Unstable condition causes higher turbulence in combination with an increase in the low frequent contribution

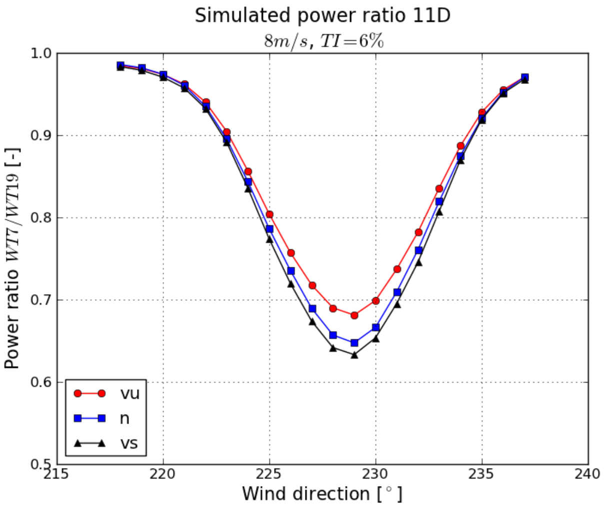


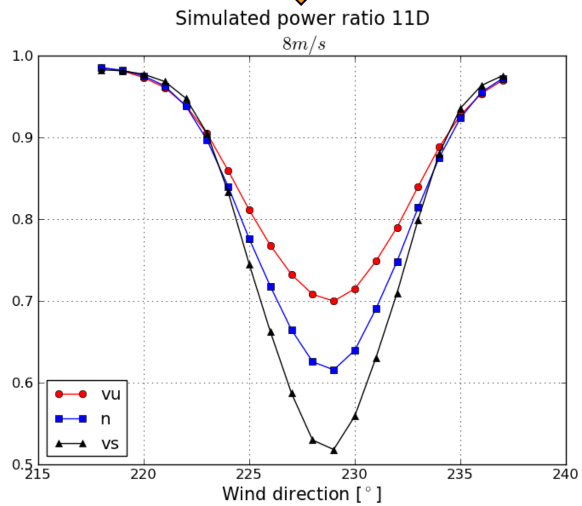


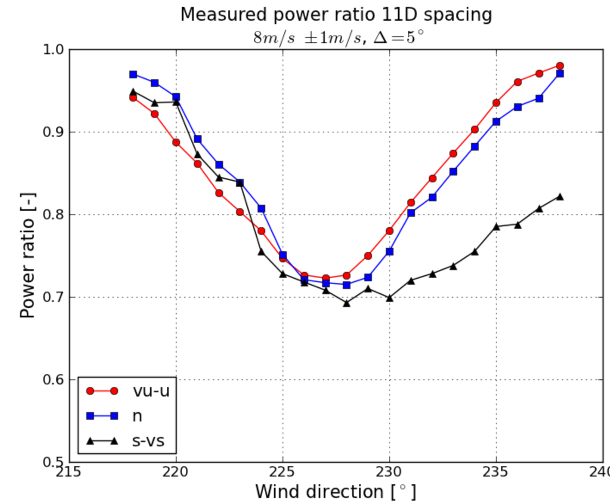


Results of stability study, Egmond aan Zee

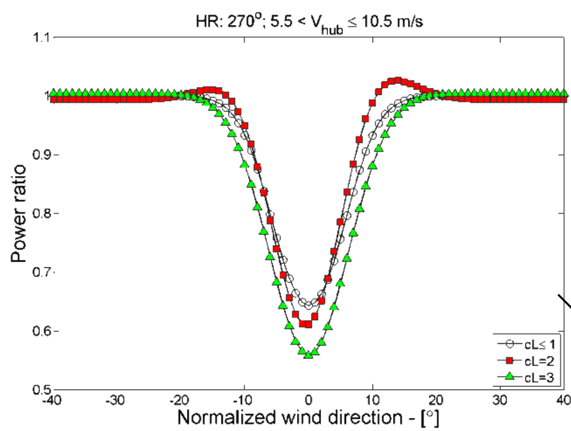
Turbulence intensity matching measured levels







Turbulence intensity constant at 6%



Measurements extracted - Too little data for final conclusions

K. Hansen et. Al, *The impact of turbulence intensity and atmospheric stability on power deficits due to wind turbine wakes at Horns Rev wind farm. Wind Energy 2011*

Summary

- The DWM model has been implemented in a light version of the aeroelastic code HAWC2, and is very fast (30min simulated in 60seconds)
- A new extension of the model for incuding effect of multiple upstream turbine, has been implemented and compared to measurements with good result.
- It has been demonstrated that wind farm production estimates can be done. Further work on the very low frequent variation in wind direction (trends) and wind direction correlation for large spacings needed to obtain perfect results.
- Effects of atmospheric stability are included by using modified turbulence for the ambient turbulence. Unstable conditions are seen to increase the production and vice versa.

Thanks to Vestas Wind Systems for the permissions to use turbine data and measurements!